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Bio-coal market study: Macro and micro-environment of the bio-coal business in Finland



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ARTICLE INFO

Article history:

Received 5 December 2012

Received in revised form

29 October 2013

Accepted 31 January 2014

Available online 1 March 2014

Keywords:

Bio-coal

Biomass

Bio-economy

Sustainable energy

Co-firing

Finland

ABSTRACT

The general purpose of this paper is to determine the current situation of the Finnish bio-coal sector, and outline a comprehensive picture of the macro and micro-environment related to bio-coal in Finland, as well as to propose, with the help of a SWOT analysis, guidelines and hypotheses regarding how the Finnish market should improve the bio-coal business for the future. The major findings of the study are: 1) the major strength of the Finnish bio-coal sector is its secured biomass supply, higher environmental credentials, and supportive policies. The clear implication here is that the entrance requirement for the bio-coal business is relatively low, “early birds” with foresight will win out; 2) the current weakness of Finnish bio-coal development is undeniable. As an entirely new business, bio-coal does not have a clear development model, which can be attributed to the little market information available, non-viable economic structure, and distribution channels which are not yet available. We would like to advise Finnish companies to work out the cost structure, profit feasibility of the bio-coal business and construct a practicable and sustainable biomass supply system; 3) the opportunities of the Finnish bio-coal sector come along with the national sustainability development policies and construction of a bio-economy. We would suggest that they focus on decentralised local economic sales, biomass supply and energy end use; 4) the crucial threat to the bio-coal sector industry comes from competition with fossil coal and other wood-based biofuels. Improving its competitiveness requires cooperation and integration along the whole supply chain.

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1. Background

Nowadays, there is a pressing need for renewable/sustainable energy solutions to deal with the extreme challenges humanity faces, such as pressure of population expansion, a

dwindling stock of fossil fuels and other non-renewable resources, deterioration of environmental health and ecological balance, and a globally intensive process of industrialization which make heavy demands on energy resources. In line with the concept of sustainable development, sustainable energy solutions should embody economic, social and environmental

Abbreviations: SWOT, strength, weakness, opportunity, threat; HTC, hydrothermal carbonization; PVO, Pohjolan Voima; CHP, combined heating and power; ISO, International Organization for Standardization; RES, renewable energy strategy; GDP, gross domestic product; R&D, research and development; GHG, greenhouse gas; PAH, polycyclic aromatic hydrocarbons.

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<http://dx.doi.org/10.1016/j.biombioe.2014.01.044>

issues, and meet the present energy needs without compromising the ability of future generations to meet their own energy needs [1]. Its renewability and higher environmental credentials has meant that bioenergy has been strongly promoted by scientific institutes and governments as a crucial solution, because substituting bioenergy for fossil fuels can reduce carbon dioxide emissions, mitigate the greenhouse effect, alleviate oil dependence, improve energy security, and conserve non-renewable resources [1,2].

Wood-based bioenergy has a significant role in the renewable energy sector in Finland, because of its substantial forest resources, developed forest industry and the well-established forest infrastructure. Finland is one of the leading countries in the production and utilisation of wood-based bioenergy. About one-fifth (85 TWh) of Finnish energy consumption is currently based on wood-based bioenergy, and Finland plans to extend this to 30% of total energy consumption (99 TWh) by 2020 [3].

There are many academic papers focused on Finnish wood-based energy in general; for example, Hakkila [4] outlined the forces driving this industry. Ericsson et al. [5] studied the related policy and its market development, and compared the Swedish market. Heinimö [6] discussed the trade in solid and liquid wood-based biofuels in Finland, While Heinimö and Alakangas [7] explored the Finnish wood-based biofuel market. There are also many studies focused on specific products such as wood pellets [8–11], wood chips [12,13], wood biomass [14–16], and firewood [17–19].

However, little attention has been paid to the Finnish wood-based bio-coal product and market. Bio-coal is new and has only partially emerged from the research stage [20]. Until very recently, the commercial production of bio-coal for industrial applications had only been launched in a small number of countries such as The Netherlands, Belgium, France and the US [21]. In Finland, there is no industrial market for bio-coal as yet. Some Finnish institutions and companies have engaged in product development and business launching programmes. At the beginning of this year, a proposal was announced to build the first large-scale torrefied pellet factory in Ristiina with an annual production capacity of 200,000 t [21]. Hence, a pioneer study on the Finnish bio-coal sector is urgent and important.

This study is intended to enhance the understanding of the challenges and opportunities of the bio-coal business in Finland. Its general purpose is to identify the current situation of the Finnish bio-coal sector, and outline a comprehensive picture of the macro and micro-environment related to bio-coal in Finland, as well as use a SWOT analysis to suggest guidelines and hypotheses regarding what the Finnish bio-coal business market should improve for future. The research questions are as follows:

- 1) What is the current state of the bio-coal business in Finland?
- 2) What are the current drivers and expected changes in the macro and micro-environment of the bio-coal business in Finland?
- 3) What are the strength, weakness, opportunities, and threats in the bio-coal macro and micro-environment in Finland?

The next part defines the terminologies associated with bio-coal and introduces the theoretical framework for the study.

The third part examines the macro and micro-environment related to the bio-coal sector in Finland. The fourth part summarizes all the important factors and analyses them using a SWOT matrix. Finally, this article will provide some future perspectives and suggestions about bio-coal development in Finland.

2. Theoretical background

2.1. Definition of bio-coal

The definition of bio-coal is rather imprecise at the moment, there being no generally accepted definition. Many interrelated terms have been used, such as charcoal, bio-char, char, torrefied wood, torrefied pellets, green coal, black chips, black pellets, and so on. There is also a variety of terms in Finnish, including *puuhiili*, *grillihiili*, *TOPpelletti*, *torefointi/paahdettubiomassa*, *biohiilipelletti*, and *biocarbon*.

Rautiainen et al. [22] defined bio-coal as a solid fuel made from biomass in a pyrolysis process (by heating in an inert atmosphere). Depending on the process conditions, the resultant solid product is either charcoal (process temperature above 320 °C) or torrefied wood (if the process temperature is between 200 and 300 °C). Both of these products are bio-coals. Tremel et al. [23] and Erlach et al. [24] interpreted bio-coal as a coal-like substance which been converted from raw biomass in an artificial coalification process called hydrothermal carbonization (HTC). Borison et al. [20] claim that “Bio-coal is a fuel produced from biomass, whose physical and chemical properties have been changed so it looks and acts to a large degree like coal.”

According to Agar and Wihersaari [25], bio-coal (or green coal) is a fossil coal substitute which is produced from renewable biomass resources in the process of torrefaction. They describe the three major properties of bio-coal as it being 1) a fossil coal substitute with high heating value; 2) having high bulk energy density, and being easy to transport, store and process; 3) having handling properties like fossil coal, such as being easy to grind. Another similar definition is that bio-coal is a dried and enhanced biomass product produced by torrefaction [26]. The Finnish consulting company Pöyry considers that bio-coal is a name for charcoal which is created by pyrolysis of biomass [27]. Fagnäs et al. [28] illustrated the compositions of bio-coal produced in the slow pyrolysis process, including the primary solid product – char or charcoal, and by-products – distillates and gases.

In summary, the term bio-coal has been defined as an umbrella concept which covers all solid thermally degraded biomass products produced in the process of pyrolysis, including torrefaction and hydrothermal carbonization with different features and applications. In the context of this paper, we accepted the umbrella view of the term, but with a focus on the solid product and medium and large-scale industrial applications such as replacing fossil coal in coal-fired power plants.

2.2. The macro and micro-environment

The theoretical framework to guide the market information environment analysis is modified on the basis of Hansen and Juslin's information environment model [29], and it includes

two sets of market information: macro environment information and micro-environment information (Fig. 1).

The micro-environment contains information such as relationships, structures and communications between all the actors involved in the supply chain. As the industrial market of bio-coal has not been established in Finland yet, it is hard to obtain business practical information in this sector. Therefore, only two categories have been made to cover micro-environment information in this study, which are “Biomass competition & the role of forest industry” and “Market activities & key players”. It is analysed in the first two sub-chapters of the results chapter. However, issues related to competition, physical biomass channels, and bio-coal distributions, business models, and supply chain management are discussed in the SWOT matrix.

The macro environment contains information such as legal framework/political, social, nature environmental, economic, demand & supply information, and technological aspects. It provides the major information of this study as macro environment information is central in the market study and policy making. Guided carefully by the macro environment model, the macro environment, including all the above-mentioned information, are analysed in six sub-chapters of the results chapter. In summary, there are altogether eight sub-chapters in the results chapter which correspond directly to the eight categories of the theoretical framework.

3. Methodology and data

3.1. Methodology

In general, there are two major types of market research: primary research and secondary research. Secondary research is “any further analysis of an existing dataset which presents interpretations, conclusions or knowledge additional to, or different from, those produced in the first report on the enquiry as a whole and its main results [30]”. It gathers any data “for one purpose by one party and then put to a second use by or made to serve the purpose of a second

party [31].” It is one of the broadest and most diffuse research methods in social sciences, especially in a market research context, due to its embracing of virtually any information that can be reused [31–33]. A secondary research (desk research) method is chosen for this study, because there is no existing market of bio-coal, and the purpose of this study is to conduct a precursory market study of bio-coal, to produce hypothesis and guidelines for its future developments in Finland.

3.2. Data

The data used in this study is mainly secondary data, including both numeric and non-numeric, obtained from publicly accessible sources. There are three major data sources in this study: general business sources (guides, directories, indexes, statistical data, trade journals, company reports, etc.), academic sources (academic publications) and government sources (regulations, government reports, press releases, statistical data, etc.). Reports by research institutions and industry association and governmental documents are the most important sources. Issues regarding authenticity, credibility, representativeness and meaning of the data have been considered during data collection.

3.3. Data analysis

Data is analysed through systematic reviews, and documentary analysis focussing on the detection of themes. The strategy of data analysis is to use the collected secondary data to answer the defined research questions in this study. All the concepts, categories, properties and dimensions are assembled, coded and analysed through a “framework”, based on thematic matrices. Guided by the information environment model, eight themes (or categories) are defined, that is, biomass resources, emerging bio-coal, political environment, economic environment, environmental issues, social environment, technical environment, and demand. Finally, the relationships of the defined themes are discussed in the SWOT matrix.

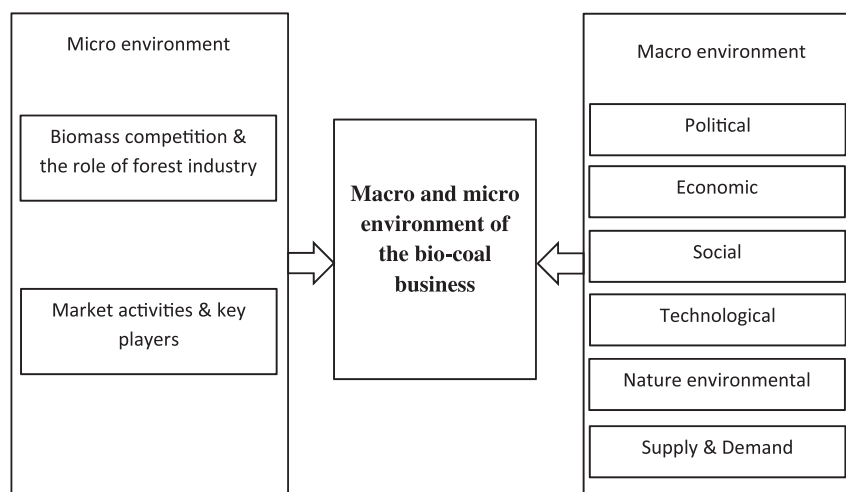


Fig. 1 – The theoretical framework [sources: [29]].

4. Results

4.1. Micro-environment of bio-coal in Finland

4.1.1. Biomass competition and the role of forest industry

Forestry land covers two-thirds of Finland's total land area, making wood and wood-based biomass feedstock abundant (Table 1). Accordingly, the main feedstock for biomass production in Finland is wood, either forest residues from thinning or logging operations, or by-products from forest industry production. Currently, over three-quarters of Finnish forest-based bioenergy originates from forest industry by-products (residues from sawmilling, and paper & pulp production) [34]. However, direct extraction of forest residues is expected to be a rapidly growing resource for forest bioenergy solutions as forest industry by-products are not going to increase in the future [36]. Other energy crops like willow and poplar are used but not significantly in energy production. The potential of agricultural biomasses (straw, reed canary grass, etc.) is also being explored.

In Finland, the forest biomass used for energy purposes was 13.8 TWh, equal to 6.9 Mm³ (solid) in 2010, which was 7 times more than 10 years ago [37]. The national target for the use of forest biomass is 27 TWh (13.5 Mm³ solid) in 2020, which means that it has to double by 2020 [38]. Currently, about two-thirds of forest biomass is used for industrial purposes and power generation (mainly used in the forest industry), and one-third for small-scale combustion in municipal heating plants [39,40]. One emerging use of biomass is converting biofuels for the transportation end uses, the estimated quantity for Finland in 2020 being 5.3 TWh [41].

Obviously, the forest industry is both the major user and producer of forest biomass in Finland. Forest energy can be adopted easily in Finland because the local forest industry: 1) advocates forest energy and has integrated fibre and fuel procurement in its upper stream supply chain; 2) has large-scale forest products production and is actively involved in the development of production technology; 3) can closely

connect forest industry, energy industry, and many biomass related business activities through the already existing downstream supply chain [4]. Therefore, it seems that the forest energy can be adopted by the Finnish forest sector easily, and biomass competition between the forest industry and the energy sector has not been observed in Finland yet [42].

4.1.2. Market activities and key players

Information related to bio-coal cannot be captured easily from public sources, statistical information is not available among the governmental and institutional resources, and Finnish companies release bio-coal related information in a very superficial form.

On a non-industrial scale, bio-coal is a seasonal commodity used for grilling and barbecuing. It relates to the Finnish custom (some say this is a national sport) of barbecuing outdoors in summer. Currently, most of the bio-coal used for barbecues is imported from the Baltic states and Poland and sold in small bags (mostly packages up to 5 kg), as a lump or briquettes or as single-use grill boxes. The volume imported was 2536 t in 2011 [43].

Additionally, there is also a small market in Finland for bio-char and distillates as a growth enhancer for plants, activated carbon to remove pollutants (purification), soil improver and a by-product application in odour prevention [22]. Finnish companies like Biolan, Preseco Oy and Biowatti Oy are active in this field. However, distillates are subject to thorough testing before getting approval from the Finnish authorities to enter the market as they are so-called “green chemicals”.

At the moment there is neither an industrial demand to market bio-coal in Finland, nor a clear price tag on bio-coal. Bio-coal's demand is being created by large-scale energy production and industrial/residential/district-heating. A commercial market for bio-coal is in its inception, characterized by very high investment costs, slow sales volumes and almost no competition as the demand is being created by the potential customers introduced to the product [44]. Interest in bio-coal in Finland is driven by large utilities such as large coal-fired power plants conducting pilot programs on integrated co-firing of torrefied biomass such as the TEKES Bio-refine program [45].

There are only a few practical bio-coal activities in Finland. For example, Kangas [46] estimated that there are about 20 bio-coal producers in Finland, whose focus is on the local barbecue market. RPK Hiili, probably the largest producer, operates two interconnected retorts producing 250 t of grill charcoal per year [22]. Ks Party Oy densifies their charcoal, imported from Russia, into briquettes. The Finnish companies Metso Power, UPM and PVO are testing integration and suitability of torrefied wood co-firing in coal plants [45]. The first bio-coal production plant in Finland is to be built in Ristiina in 2015 on a total budget of EUR 30–40 million, and a planned annual production capacity of 200,000 t [21].

4.2. Macro environment of bio-coal in Finland

4.2.1. Policies related to bio-coal

Finland's national energy and climate policies go hand in hand, employing a cross-sectoral approach and striving to

Table 1 – Forest biomass resources in Finland.

	Amount	Energy
Biomass directly from forests		
Forest area	26.3 Mha	
Annual growth of forest biomass	110 Mm ³	
Annual drainage of forest biomass (average)	85 Mm ³	
Annual final fellings (average)	172,000 ha	
Annual thinnings (average)	438,000 ha	
Annual of forest residue resources (theoretical)	45 Mm ³	324 PJ
Annual forest residue potential for energy use (technical)	11.4–20 Mm ³	82–44 PJ
Biomass from forest industry production		
Sawdust	1.69 Mt	12 PJ
Bark	8.39 Mm ³	54 PJ
Chips and shavings and other industrial residues	0.95 Mm ³	7 PJ

[34–36].

achieve a sustainable and carbon neutral energy system. Table 2 summarises the most important policies and measures related to bio-coal in Finland.

As illustrated by this table, Finland's National renewable energy action plan plays a key role in the bio-coal sector and sets the baseline for its development. The Finnish government has applied many other measures to implement its renewable energy policy, including energy taxation, tax relief, production and investment subsidies, funding for R&D, and incentives for production and end uses. Bio-coal is not specifically mentioned in the plan, but could fit into the pellets group. Currently there are no national incentives to support use of pellets (bio-coal) for heat and electricity production. However, according to Alakangas and Vesterinen [48], measures to promote the use of pellets are being prepared.

Renewable Energy Sources (RES) support schemes in 2011 for the electricity sector was EUR 100 million (the feed-in tariff is allocated to electricity production, but it also indirectly promotes renewable heat production); EUR 31 million for the heating sector and for the transport sector EUR 107 million [49]. In 2012, investment subsidies were as follows: EUR 34 million for renewable energy, EUR 100 million for a transport biofuels demo plant, EUR 7 million for the biofuels development programme, and EUR 15 million for energy efficiency [47]. According to the Ministry of Finance [49],

renewable energy production subsidies totalled EUR 98 million in 2012.

Since 2011, energy taxation has been based on the energy content (levied on bioenergy as well), CO₂ emissions (does not apply to energy produced from biomass) and local/particle emissions that have adverse health effects. Additionally, Finland supports its energy intensive industries with a lower electricity tax and a tax refund system. Farmers also receive energy tax refunds which is an excise duty refund for electricity and oil products used for agricultural purposes. So far, Finnish tax breaks do not promote the consumption of bio-energy, targeting a decrease production costs and maintaining the international competitiveness of business instead.

The Finnish government has determined to support utilisation of wood for energy, particularly in terms of local solutions. For example, a subsidy of 0.69 EUR kWh⁻¹ is provided for electricity produced from forest chips [6]. The government also monitors the use of energy subsidies for small diameter and low-grade wood to ensure that subsidies do not distort competition or the acquisition of wood raw material.

As mentioned in Table 2, the Finnish government supports R&D in the bioenergy sector. For example, Tekes, the Finnish Funding Agency for Technology and Innovation, is the main public funding organisation for R&D. BioRefine, one of its programmes, focuses on bioenergy, and has a total budget of

Table 2 – Overview of bio-coal related policies and measures in Finland.

Name of measure	Type	Targeted group/or activity	Start dates
National energy and climate strategy	Regulatory	Public administration, energy sector	2001
National renewable energy action plan	Regulatory	Renewable energy	1999
Electricity Market Act	Regulatory	Guaranteed access to the grid	2004
Sustainability criteria for biofuels and bioliquids	Regulatory	Biofuel producers and distributors	2012
TC 383 "Sustainably produced biomass for energy applications"	International standard	Biomass and energy sector	2008
ISO 13065 Sustainability criteria for bioenergy	International standard	Bioenergy sector	
Feed-intariffscheme	Financial	Electricity produced from renewable energy sources	2011
Act on production support to electricity from renewable energy sources	Financial	Production support to biogas, small-scale CHP, woodchips	2012
RES support schemes	Financial	Electricity, heating and transport sector	
Energy support (government decree on general terms and conditions for granting energy support)	Financial	Energy sector	The renewable scheme will be in force as of 2013
CO ₂ tax	Financial	Energy sector	1990
Fuel tax (Act on exercise tax on electricity and certain fuels)	Financial	Energy producers and end users	1996
Energy tax	Financial	Energy producers and end users	2011
Decree on Repair, Energy and Health Hazard Assistance for Housing	Financial	Privateresidentialhouseholds	
Decree on assisting bioenergy production	Financial	Promoting bioenergy production	
Investment subsidies for farms	Financial	Farm heat plants and biogas plant	
Decree on support to farm energy plans	Financial	Farm heat plants and biogas plant	
Act on the Financing of Sustainable Forestry	Financial	Non-industrial and private forest owners	2007
Energy support for small trees	Financial	Forest owners	2012
Energy support to low-grade timber	Financial	Forest owners	
Cleanenergyprogram	Financial	Renewable energy production	2012
BioRefine (Tekes programme)	Financial/ R&D	Biomass refining	2007–2012
Groove (Tekes programme)	Financial/ R&D	Renewable energy	2010–2014
Green Growth (Tekes programme)	Financial/ R&D	Energy and material efficiency	2011–2015

[5,39,42,47,48,57].

EUR 250 million covering 137 projects [45]. In particular, there are five bio-coal related projects funded by Tekes at this moment, one called the Torrefied wood project (duration 2010–2012, co-financed budget EUR 361,000), which aims to create conditions for rapid commercialization of agricultural and wood products torrefaction technology in Finnish and European markets [45].

In summary, the legal framework for the Finnish bio-coal sector, which follows the Finnish renewable energy and climate strategy, has been well-established. Financial incentives for the bio-coal sector cover raw material supply and R&D well, but, tax rebates, investment incentives and production incentives are unclear in this sector, and lack specific support for bio-coal end users.

4.2.2. Economic environment to bio-coal

There are several important features of the Finnish energy economy related to the bio-coal sector: 1) the traditional energy sector is highly dependent on imported energy; 2) the traditional energy sector is highly concentrated; 3) the Finnish energy industry owns a variety of energy sources; 4) non-viable bio-coal economic feasibility.

The Finnish economy is highly dependent on the global export market and imported energy sources. However, it has experienced a deteriorating trade balance for last ten years, with over a third owing to imported energy [50]. In 2011, the total value of imported energy in Finland was EUR 13.55 billion, and the proportion of net imported energy of total energy use was about 55% [51]. Thus the target of reducing economic dependence on imported energy, and increasing the use of domestic energy sources is crucially important for the Finnish economy, and may drive Finland to be a leading country in a new sustainable economic area called “bio-economics”. As defined by Gustafsson et al. [52] “a bio-economy is perceived as an economy based on sustainable production and conversion of biomass to be used as a major resource in a wide variety of industries.” The annual bio-economy is valued at EUR 2000 billion, which provides 22 million jobs in the EU [53]. The current Finnish bio-economy value is about EUR 50.75 billion, which accounts for 13.5% of the total Finnish economy values [54]. The bio-coal sector apparently falls into the needs of constructing the bio-economy.

Finland has one of the highest energy intensities in the world which amounts to 6.03 TOE per capita. The energy sector is concentrated among large-scale players [50]. For example, in the electricity market, there are about 120 generation companies. However, the production capacity is highly concentrated in a few large corporations like Fortum Oyj, PVO, and Heat Oy, who together produce about 58% of Finland’s electricity [55].

The Finnish government plays a significant role in the energy sector through state-owned enterprises (such as Ima-tran Voima, Neste, and Vapo) and monitors energy prices by setting applicable regulations or by means of taxes and tariffs [56]. In contrast to the large-scale, concentrated traditional energy fuel players, the best economic scale for the bio-coal sector should be a decentralised local solution because of knowledge and biomass availability [52]. It is strategically important to have bio-coal production location close to feed-stocks and end users because long-distance transportation of biomass is not feasible [52]. Thus, the economic scale for bio-

coal fits the model of a bio-economy consisting of concepts of localization in operations, value-adding in products, and variety of small-scale business solutions perfectly.

Another feature of Finland’s energy economy is the versatility of production structures, which protect the Finnish economy from unforeseeable energy price fluctuation or disruptions in supply [57]. The primary energy sources in Finland are oil, coal, natural gas, indigenous fuels, hydropower and nuclear power. Bioenergy, hydropower, geothermal, wind power and solar power are the major renewable energy sources [51]. In 2010, the share of renewable energy of total consumption in Finland was 32.2%, and the target is 38% in 2020 [58]. The development of bio-coal extends the versatility of the Finnish energy system and improves its self-sufficiency, and sustainable energy security.

However, so far the economic feasibility of bio-coal sector in Finland is unclear insofar as there is no clear reference for the price of mass-produced bio-coal. In the US, scale and configuration of equipment differs in the range from 1 to 6 t h⁻¹, and commercial unit cost projections varies from USD 50 000 to USD 3 million [59]. The US price of bio-coal (specifically, torrefied wood) is about USD 150 to USD 200 t⁻¹, and in the European market an average of USD 270 t⁻¹ [59].

However, price information related to the Finnish market has been largely neglected. The projected cost structure of bio-coal in the Finnish market is illustrated in Table 3. The projected bio-coal operation cost in the Finnish market is about EUR 300 t⁻¹ (EUR 33.7 MWh⁻¹), and the market price is predicted to be about EUR 350–450 t⁻¹ (EUR 40–50 MWh⁻¹) [44]. The price level for conventional wood pellets in Finland was about EUR 35 MWh⁻¹ in 2011 [60], thus some predictions that the relative price of bio-coal will have to compete with other biofuels, e.g., Flyktman et al. [61], provided an indicative price of bio-coal of EUR 35 MWh⁻¹.

Essentially, bio-coal will have to compete with coal, the price of which was EUR 31.97 MWh⁻¹ [51] in Finland in late 2011. A competitive cost of bio-coal should thus be less than the cost of coal plus CO₂ emission allowances. For example, a calculation formula has suggested by Bagramov [44]: “Competitive price of bio-coal = Price of fossil coal + CO₂ allowance × net efficiency 36%”. So if we use EUR31.9 MWh⁻¹ as price for coal, and EUR 20 MWh⁻¹ for CO₂ allowance, the calculated competitive price of bio-coal will be EUR 39.1 MWh⁻¹.

4.2.3. Social environment for bio-coal

The bio-coal business enhances regional policy, employment and energy security significantly, because its activities evolve

Table 3 – Bio-coal production costs indications (EUR MWh⁻¹ biocoal).

Production cost items	EUR MWh ⁻¹ biocoal
Biomass	24.7
Man power	1.8
Electricity	3
Maintenance cost	3
Heat for drying	1.2
Total cost	33.7
Retail price	40–50
[44].	

around local resources and value addition, leading to diversified local economic development. Bio-coal production can be expected to provide new jobs and offset the continuously decreasing jobs in conventional wood processing and the pulp and paper making sector. In Finland, local energy production has the potential to become increasingly important as the forest industries restructure their operations and cut down production, and the labour laid off from the traditional forest industry can be conveniently placed in the new bioenergy sector. In general, the renewable energy package in Finland is predicted to create 15,000 new jobs [50]. More jobs can also be created in related industry such as clean technology. Finland aims to create 40,000 new clean tech jobs by 2020 [62].

The development of the bio-coal sector will create new opportunities for rural development. For example, bio-coal production enhances the need for forest management, operation and biomass supply. Local self-employed forest operators, forest owners and farmers can benefit from these sectors. Small entrepreneurs and local communities can also be involved in the distribution of bio-coal based energy, such as cogeneration CHP, in which Finland is one of the world leaders in cogeneration economies and applications. There are about 500 CHP plants in Finland with an average heating capacity of 580 kW [63]. A small-scale CHP business can be operated by a local forest owner, usually a farmer, providing heat to a small community or a local building, such as a school. Currently, the fuels used in these small-scaled CHP are wood chips and pellets. Bio-coal could be one of substitute fuels, which are produced locally for the CHP applications. In addition, local governments play a central role in bio-coal production and consumption, because local governments traditionally own the local energy companies and join major decision-making bodies involved in infrastructure construction and community development. Thus, production and consumption of bio-coal can be a municipal decision as well.

On the other hand, a study indicated that the increase in bioenergy use under current technologies in Finland would slow down its GDP growth and decrease its employment [64]. The cost to society mainly arises from the shift towards costlier inputs than fossil energy, thus leading to decreased economic productivity [64]. Accordingly, we can estimate how much the increase in replacing fossil coal with bio-coal will cost society in growth foregone and its impacts on employment. In contrast, another study indicated that the production and use of bio-coal leads to positive private profits (positive net social benefits) in the short run [65]. Nevertheless, the use of bio-coal will help to achieve the Finnish emission reduction goals and sustainable development in general, and will contribute to the economy and employment development in the long run.

4.2.4. Environmental issues for bio-coal

In 2010, total greenhouse gas emissions amounted to 74.6 Mt of CO₂ in Finland, and the reduction target for Finland is 16% by 2020 from 2013 [51]. The Finnish forests play a significant role in this field, by binding about 50% of the CO₂ emissions in Finland (amounting to 30 Mt of CO₂ annually) [37]. In particular, the renewable energy sector could produce of emission reductions equivalent to 4–5 Mt of CO₂ in 2010, and contribute 25–30% of its national reduction target in total by 2020 [66,67].

Bio-coal and other by-products produced in Finland are considered to be CO₂ neutral because its biomass resources are from sustainably managed forests and about 95% of Finnish forests are certified under PEFC [68]. Replacing coal with bio-coal is also likely to lead to CO₂ reductions and thus help mitigate climate change [65].

The EU Commission has started discussing sustainability criteria for biomass. In Finland, since these criteria are expected to involve additional costs and increase the price of energy, the Finnish government has a sceptical attitude towards the additional criteria. However, if the directive is passed, Finland will have to implement it.

Bio-coal contains higher energy credentials compared to wood chips and pellets, such as mass/energy balance, calorific value, energy density, moisture content and degradability [65]. One significant example is that the torrefaction process releases energy that impacts the total energy balance of the production process. Important environmental issues in the different parts of bio-coal supply chain are summarized in Table 4.

In general, the differences in GHG emissions balances over the life cycle between fossil coal and bio-coal, being 262 kg CO₂-eq MW h⁻¹ of fuel, in other terms, the total reduction in GHG emissions in replacing 1 t coal with 1 t bio-coal is about 1.6 t CO₂-eq over a time horizon of 100 years [65].

4.2.5. Technical environment for bio-coal

Technologies of the bio-coal sector include harvesting of biomass, chipping, transportation, refining, and conversion. The following table discusses the major technologies involved with bio-coal (Table 5).

In Finland, the major biomass feedstock for bio-coal production is logging residues and stumps gathered from regeneration felling, and small-diameter energy wood from young forest restoration and first thinning [69]. Logging residues and small-sized trees are normally chipped at the roadside and transported by trucks to plants, which is established as the lowest supply costs within a transportation range of 30–200 km. Overall, the supply chain for roadside chipping is matured and tested, i.e., the work flow (loading, unloading procedures and chipping) and techniques (chippers, self-unloading trucks) [14]. In terms of transportation, since short distance transportation is the most cost-efficient, bio-coal can easily find its supply chains in Finland just as with pellets.

Bio-coal is produced through a process called pyrolysis, in which wood and other organic material is heated in the absence of oxygen. If the highest temperature in the process is above 300 °C, the solid product is charcoal. If the temperature is between 200 and 300 °C, torrefied wood is formed. Hydrothermal carbonization (HTC) is another technique currently under development to produce bio-coal. HTC takes place in pressurized water at 200–250 °C at or above saturation pressure. The HTC process is slightly exothermic and the product is hydrophobic.

In Finland, the major bio-coal technology is based on torrefaction, which means it is produced from forest chips that are dried and then roasted at 200–300 °C in an oxygen-free environment for approx. 12 min. There is still room for technical innovation to improve sustainable development, for

Table 4 – Environmental issues related to the bio-coal supply chain.

Bio-coal SC phases	Environmental issues
Production of biomass	• Effects of residue removal on forest ecosystems: disturb nutrient balance, risk of erosion and leaching, impact on forest biodiversity, and decline in the amount of decaying and dead wood. • The machines used for forest operations consume diesel fuel, and thus emit emissions • Decrease in forest soil carbon stock
Logistics and transportation of biomass	• Decomposition reactions that take place in storage heaps: material and energy loss, nutrient leaching • Direct emissions from diesel fuel and indirect emissions from the production of electricity
Production of bio-coal	• GHG and other emissions from auxiliary energy use • Emissions encountered in drying the biomass and combustion of the torrefaction gas • Noise and dust production • Energy loss
Transportation of bio-coal	• Ship transport does not cause major environmental impacts per unit of biofuel • Road transportation has a bigger effect on the GHG and air emissions • Frequent truck transport also causes other adverse local impacts
End-use	• CO₂ emissions of bio-coal combustion are generally not accounted for as a GHG • Produce other GHGs: methane and nitrous oxide • Replacing coal with bio-coal reduces mercury emissions, sulphur dioxide emissions, and NO_x emissions, and should not result in significant PAH or heavy metal emissions • Small-scale combustion of bio-coal generates high levels of fine particulate matter emissions • Co-combustion of bio-coal and coal generates less ash than coal combustion alone • Reuse or disposal of ash
[65].	

example, in bio-coal by minimizing waste and pollution formed during its processes.

Co-firing with coal has been identified as one of the least expensive and most efficient conversion technologies for bioenergy [24,70]. Bio-coal provides an opportunity to

minimize retooling the power plant, extend the lifetime of facilities and reduce CO₂ emissions through co-firing with coal. The heating value of bio-coal is 20.9 GJ t⁻¹ (5.8 MWh t⁻¹). The use of bio-coal will substantially increase the potential ratio of co-firing in standard coal-fired power

Table 5 – Major bio-coal production techniques in Finland.

Technology	Description	Comments
Woody biomass harvesting	Source: • Residue of logging operations • felling of small-sized trees • Energy crop (willow, poplar, etc.) Mechanized harvesting systems: • the traditional two-machine (harvester and forwarder) system, • the harwarder system (the same machine performs both cutting and forest haulage to the roadside)	• Harvesting techniques integrated into the forest industry have developed. • Biomass harvesting forest production and forestry residues. (Woody energy crops are insignificant.) • Expansion of feedstock choice
Chipping	• At the roadside, by a separate chipper and transportation truck, most common. • At the end use site (usually stump crushing) • At a terminal (usually stump crushing)	• Forest residue is stored before or after chipping (or both) in heaps at the roadside near the felling site. • It is less common to use an integrated chipper and chip truck at the roadside. • Chipping at the harvesting site is no longer used
Transportation	• Generally done by truck • Long distances can employ train or ship	• Loose chips from chipping terminal are transported to a heating plant by an ordinary chip truck or tractor trailer
Refining with pyrolysis	Solid product of pyrolysis is bio-coal: • Peak temperature 200–300 °C → main product torrefied wood • Peak temperature above 300 °C → main product charcoal Process alterations affect final products and their yields (for example, in flash pyrolysis the main product is liquid fuel, bio-coal is a by-product, utilized within the system immediately as an energy source)	• Bio-coal processing techniques have not been widely commercialized yet (know-how available but show-how lacking). • Possible densification of refined biomass (into pellets and briquettes) may improve the efficiency of transportation and storage. • Improving milling behaviour • Enhancing storage properties of pellets • Improving combustion stability/efficiency; e.g., drying less volatile fuel, and recycling of torrefaction gases
Conversion	• Directly milled • Co-firing with coal	• Great co-firing rate is up to 100% and does not require power plant retooling

plants (up to 100% in comparison to about 10% based on wood pellets) and will allow co-feeding woody biomass in industrial-sized coal gasifiers. In Finland, co-firing bio-coal with coal is still in the experimental stage, and full-scale co-firing tests have not been conducted because no full-scale local bio-coal supply exists.

4.2.6. Supply and potential demand for bio-coal

Bio-coal will probably evolve as a refined form of pellets and as a substitute for non-renewable fossil fuels, coal in particular. Price competitiveness will be the determining factor for the scale of demand and supply, while Finnish companies are not yet motivated to invest in bio-coal because of unpredictable profitability. Currently, there is no real industrial scaled supply of bio-coal in Finland, only some production projects under discussion and planning. The major demand for bio-coal can be expected from the following end-use markets: coal-fired power plants, district heating (CHPs), and small-scale use.

Replacing (co-firing) fossil coal with bio-coal at current coal-fired power plants will be the major demand for bio-coal in Finland. According to Statistics Finland, Finland consumed 4.2 Mt of coal for generating electricity and heating in 2011, corresponding to 29.4 TWh in energy content, and accounted for about 12% of total primary energy consumption [71]. Some pilot projects on bio-coal co-firing are taking place now and more are expected. The outcomes of those projects will encourage industrial demands for bio-coal in the future. The potential market size of replacing coal with biomass fuels in Finland will be about 7–8 TWh annually⁻¹ [72], in which bio-coal should occupy a major proportion. Another estimate made by Helsingin Sanomat [73] was that half of the coal used in Finland's coastal coal-fired power plants could be replaced using bio-coal.

District heating/CHP in Finland will be the second largest market for bio-coal in the future. District heating accounts half of the total heating market, 80% of which is produced by CHPs [74]. In total, 666 stationary heating plants and 392 transportable heating plants cover all 171 towns. The wide distribution of the heating plants leads the demand for bio-coal which is produced locally on a small-scale and based on local biomass resources. District heating consumed 65.1 TWh of fuel in 2010 and about half of the fuels were gas and oil. The rest consumed fuels, including coal (21.6%), peat (17.8%), and other wood-based biomass fuels (16.3%), can be potentially replaced by bio-coal without retooling for current equipments [74]. In summary, more than half the fuel consumed in district heating can be replaced by bio-coal.

In addition, small-scale central housing heating systems provide potential demand for bio-coal. In Finland, there are about 250,000 small-scale central housing heating systems in farms, single-family houses and larger buildings in sparsely populated areas. Currently, split wood logs/firewood (4.9 Mm³), wood residues (1.3 Mm³), chips (0.5 Mm³), and wood pellets (burnt in 20,000 boilers; about 60,000 t) are the major fuels for these small-scale users [7,75]. Additionally, there are about 300,000 oil-heated single-family houses which consume 13.9 TWh of light fuel oil annually [9,75]. If half of this light fuel oil can be replaced by bio-coal, the demand will be over a million tons. In summary, wood-based small-scale central

house heating systems and light fuel oil based heating systems in single-family houses have great potential for consumption of bio-coal in the private sector, but additional cost and technical development need more specification.

5. Summary, conclusion and discussion

Table 6, using a SWOT analysis, summarises the current states and macro and micro-environment information related to bio-coal in Finland, showing clearly the implications for the future development of the Finnish bio-coal sector.

The major strength of the Finnish bio-coal sector is its secured biomass supply, higher environmental credentials, and supportive policies. Compared to other wood based bio-fuels, such as wood pellets, bio-coal is an optimal choice for co-firing in standard coal-fired power plants with existing current energy consumption technology, as the ratio of co-firing is much higher than other wood based biomass. In addition, bio-coal has higher added values than other wood based biofuels. Except the solid coal, there are also liquid and gas forms of by-products which can be used for multiple end uses such as soil improvers, activated carbon, and odour prevention, etc.

To the industry sector, this study clearly implies that Finnish companies should be aware of this new business opportunity, because it embraces a huge potential to grow quickly in the Finnish market. In particular, the Finnish forest sector should take advantage of being a pioneer in this business. The entrance requirement currently is relatively low and there is almost no competition, so that “early birds” with foresight will win business. On the other hand, since bio-coal is a perfect solution for the sustainable energy supply in Finland, governments should add it to its energy policy, and motivate and support the development of bio-coal in Finland with legislation and facilities. In particular, governments and investment institutes should provide sufficient funds or investment for the launching periods of bio-coal projects.

The current weakness of Finnish bio-coal development is undeniable. As an entirely new business, bio-coal does not have a clear development model, which can be attributed to the lack of market information, non-viable economic structure, and non-existent distribution channels. We would like to advise Finnish companies and research institutes to improve their know-how and work out the cost structure and potential profitability of the bio-coal business urgently. Questions need answers, such as additional societal cost in replacing fossil coal, production investment, profitability with and without regulatory support, investment in R&D.

As discussed above, under current conditions, bio-coal is costlier and needs regulatory supports such as CO₂ allowance in order to compete with fossil coal. In the beginning, replacing bio-coal with fossil coal requires huge investments in setting up infrastructure and distribution system, developing technology, upgrading production facilities (the projected investment is EUR 30–40 million for a plant with an 200,000 t annual production capacity), and modifying applications (e.g. investment in co-firing technology and equipment). Later, the cost of bio-coal will be significantly reduced with the enlargement of production, increase of related technology application, and maturity of the market. At the

Table 6 – A SWOT analysis of the bio-coal sector in Finland.

Strength	Weakness
• Substantial forest biomass. • Tradition in use of wood as energy in the household and industry. • World-leading forestry industry in Finland, and forest energy which can be easily adapted to the Finnish forest sector. • No competition in the bio-coal sector yet. • Optimal product for co-firing in coal-fired power plants. • Many measures enforced by the Finnish government to implement its renewable energy policy, which is in favour of bio-coal. • Intensive R&D in the bio-coal sector. • Improving the versatility of the Finnish energy system, its self-sufficiency, and sustainable energy security by developing bio-coal. • Significantly enhances regional policy, employment and energy security by the bio-coal industry. • Reducing CO₂ emissions by replacing coal with bio-coal. • CO₂ neutrality of bio-coal and other by-products produced in Finland. • Superior environmental credentials of bio-coal compared to other wood based bio-fuels.	• Currently, the main wood biomass is by-products of the forest industry; the use of biomass directly from forests is not yet mature. • No existing well-structured biomass market; weakness due to the new market. • Poor knowledge of bio-coal among end users. • Not easy to trace bio-coal activities in Finland. • No existing industrial demand for bio-coal in Finland. • Uncertain economic feasibility of bio-coal production in Finland. • High investment costs. • Price competition with coal and other bio-fuels. • Lack of quality standards and certification. • No national incentives to support use of bio-coal. • Effects of residue removal on forest ecosystems. • Emissions during the harvesting, transportation, and production process.
Opportunity	Threat
• The national target for renewable energy in favour of bio-coal production. • Big potential markets and end uses both on the industrial scale and small-scale householders. • Growing market for bio-char and distillates as soil improvers, activated carbon, and odour prevention, etc. • Bio-coal complying with the construction of the bio-economy. • National sustainability development needs decentralised local economic scale of bio-coal production. • Rural development benefiting from the development of the bio-coal industry. • High growth potential.	• Lack of efficient and economical distribution system of biomass and bio-coal. • Competition with fossil coal and other wood-based bio-fuels. • Product and technology development still in infancy, the long launching period.

same time, the price of fossil coal will be absolutely continually increasing. It is predictable that the break-even point can be made even without CO₂ allowance in the near future.

Moreover, although Finland is well known for its substantial forest biomass, it has not yet established a direct extraction system for forest residues. There is an urgent need to build a practical and sustainable biomass supply system. This will not only benefit the future bio-coal sector but also other wood-based biofuels and the forest cluster in general.

The opportunities of the Finnish bio-coal sector come along with the national sustainability policies and the construction of a bio-economy. Since the policy framework and theoretical foundations for the bio-coal sector have been built, companies intending to enter this area should define their optimal business models. We would suggest that they focus on decentralised local economic sales, local biomass supply and local energy end use. In other terms, the bio-coal sector should contribute to the improvement of local social, economic and environmental issues, to contribute to the management of climate change and sustainability.

The crucial threat for the bio-coal sector industry comes from competition with fossil coal and other wood-based bio-fuels. The competitiveness of bio-coal is not overwhelmingly strong. The product and technology development, market and supply chain construction are still far from maturity. There are lots of spaces for Finnish companies to improve, especially

in improving the competitiveness of bio-coal. This requires cooperation and integration across the whole supply chain, from the biomass down to the end users, and will involve participation from multiple stakeholders. In addition, co-firing bio-coal with fossil coal and other biofuels can be a perfect point at which to introduce bio-coal to the market with the current energy consumption technology and market structure. In this way, it turns competition into cooperation.

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